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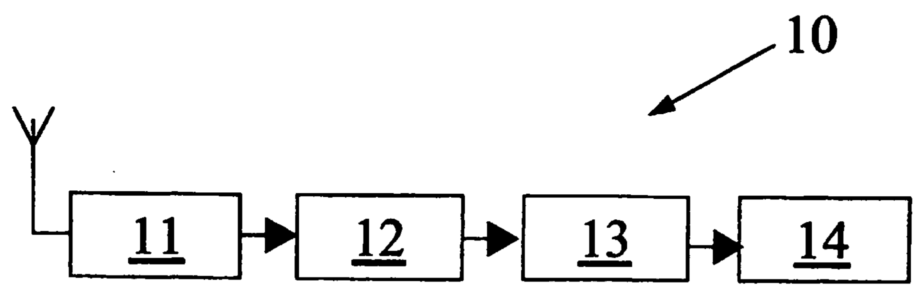


WO 01/03312 A1

(57) Abstract: A multi-standard digital receiving apparatus adaptable to reception of a service from among a plurality of services comprises in cascade an input analog section (11), an analog-to-digital converter (12) and a digital signal-treatment section (13, 14). The analog section (11) has a pass band suited to treatment of a signal having bandwidth at least equal to the bandwidth of the widest channel of all the services of the plurality and the analog-to-digital converter (12) in addition to analog-to-digital conversion carries out filtering with bandwidth near the bandwidth of the service selected to be actually received from among all those of the plurality.

MULTI-STANDARD RECIEVING APPARATUS AND METHOD OF DEFINING PARAMETERS THEREIN

The present invention relates to a multi-standard digital receiver. In particular it relates to a digital receiver structure which is advantageous for the provision of software-defined receivers. The present invention also relates to a method for the design of parameters for said apparatus.

The existence and development of a number of mobile radio communication standards or services make digital receiver structures readily adaptable to different standards ever more interesting. In this class of receivers the software defined radio (SDR) ones are still the most interesting.

The possibility of processing signals in conformity with a broad variety of bandwidths and modulation diagrams is a crucial characteristic of SDRs and heavily influences receiver design.

Unfortunately, in making digital receivers it is still necessary to have an analog input part. In the prior art there are a certain number of functions including channel selection, interference filtering et cetera performed in initial analog stages. The signal obtained at output from these stages is then converted into digital to continue its processing in a fully digital manner.

While the digital part of the receiver can be implemented by software and then adapted rapidly to operation with a number of standards, the analog part has to be redesigned each time or in any case modified physically. On the other

hand, with presently known SDR radio structures the desire to handle the signal in digital as much as possible conflicts with the computational capacity of present digital technology.

The general purpose of the present invention is to remedy the above mentioned shortcomings by making available an innovative digital radio structure in which digital signal treatment is initiated further upstream than is done in digital radio of known structure while at the same time keeping the computational power necessary for the practical production of SDR radios relatively limited. Another purpose is to make available a method for selection of the apparatus parameters.

In view of this purpose it was sought to provide in accordance with the present invention a digital receiving apparatus adaptable to reception of a service from among a plurality of services and comprising in cascade an input analog section, an analog-to-digital converter and a digital signal treatment section and characterized in that the analog section has a pass band suited to treatment of a signal having bandwith at least equal to the bandwidth of the widest channel of all the services of the plurality and in that the analog-to-digital converter in addition to analog-to-digital conversion carries out filtering with bandwidth near the bandwidth of the service selected to be actually received from among all those of the plurality.

Again in accordance with the principles of the present invention it was sought to provide a method for setting operating parameters in a digital receiving apparatus

adaptable to reception of a service from among a plurality of services and comprising in cascade an input analog section, an analog-to-digital converter and a section for digital treatment of the signal with the analog section supplied with a pass band suited to treating a signal with bandwidth at least equal to the bandwidth of the widest channel of all the services of the plurality and with the analog-to-digital converter which in addition to analog-to-digital conversion provides filtering with bandwidth near the bandwidth of the service selected to be actually received from among all those of the plurality with the analog-to-digital converter comprising a Sigma-Delta converter in which are definable a transfer function $H_X(z)$ for the signal and a transfer function $H_N(z)$ for the noise with the method comprising the steps of:

- optimization of the noise transfer function, and
- optimization of the zeros of the signal transfer function.

To clarify the explanation of the innovative principles of the present invention and its advantages compared with the prior art there is described below with the aid of the annexed drawings possible embodiments thereof by way of example applying said principles. In the drawings:

- FIG 1 shows a block diagram of a digital receiving radio structure,
- FIG 2 shows a Sigma-Delta ADC converter of a digital radio provided in accordance with the present invention,
- FIG 3 shows the interference mask of a GSM signal in the worst case, and

- FIG 4 shows the response in frequency of an ADC converter in accordance with the present invention in an embodiment for GSM transmission reception.

With reference to the figures FIG 1 shows the general structure of a digital receiver indicated as a whole by reference number 10 and comprising an analog input section 11 which receives the signal $v_r(t)$ and gives at output a signal x(t) which is sent to an analog-to-digital converter (ADC) 12. At the converter output there is a digital signal y(nT) which is applied to a digital filter 13 and then further processed in digital by the digital section 14 of the receiver. The analog stage carries out all those functions known to the those skilled in the art to make the received signal suitable for treatment by the ADC converter.

The radio apparatus 10 is the multi-standard type i.e. it must be adaptable to the reception of a standard or service from among a plurality of standards or services. For our purposes these services are characterized by fp frequencies in which the channel pass band ends and fs frequencies in which the interdicted band begins.

In accordance with the present invention the analog section is accomplished to have a pass band suited to treatment of a signal with bandwidth at least equal to the bandwidth of the widest channel of all the services of the plurality.

In other words the analog stage limits the bandwidth of the received signal to the widest bandwidth of those of the services of the plurality which it is intended to be receivable by the receiver.

With this bandwidth in the analog section, in case of reception of services with bandwidth narrower than the maximum planned the converter will with all probability receive at input a high quantity of interference. The conventional solutions proposed for the problem of ADC conversion in digital receivers and in particular software defined ones consist of second order Sigma-Delta converters, i.e. second order Sigma-Delta modulators followed by a decimator filter. This structure ensures a high signal to quantization noise ratio because the modulator colors the quantization noise, takes it out of the useful channel and permits use of digital filtering which removes the noise in the attenuated band. The weakness of the known solution lies in the fact that it does not introduce any kind of coloration on the useful signal input (in a known second order Sigma-Delta modulator the signal transfer function is a simple unitary delay) and therefore does not allow for the presence of interferers. If allowance is made for the interference mask it is noted that the digital filter required at the converter output has a rather high order.

To avoid the shortcomings of the prior art it is sought in accordance with the present invention to employ in combination an analog stage with band at least equal to the widest of those of all the services which it is desired to manage and a converter which reduces the power of the interferers already in the Sigma-Delta modulator so as to introduce a first filter stage in the ADC converter stage.

As seen below, the modulator in accordance with the present invention can take advantage of bandwidth knowledge of the useful channel and of the interference characteristic to introduce an attenuation of the interference while keeping the spectrum of the useful channel unchanged.

FIG 2 shows a Sigma-Delta converter used in accordance with the present invention. This converter 12 is a particular embodiment of a Sigma-Delta modulator which uses a linear filter with fourth order feed back.

The signal X(z) input to the converter is weighted with the coefficients $\mathbf{b}_i$ and applied to the adders which receive the feedback weighted with the coefficients $-\mathbf{a}_i$ and coming from a digital analog converter (DAC) which in turn receives the output value Y(z) at input. The error signal output from each adder is weighted with the coefficient $\mathbf{c}_i$ and sent to an accumulator $(z^{-1}/(1-z^{-1}))$ to reach the adder of the next stage. The last adder receives only the error signal and the input X(z) weighted with the coefficient $\mathbf{b}_5$ and its output is sent to a quantizer 15, e.g. a 1. Local feedback with coefficient $-\mathbf{g}_i$ can also be provided.

The structure of FIG 2 can be thought of as a linear system with two inputs and one output and hence described by an assembly of four matrices {A,B,C,D}:

$$s(n+1) = As(n)+B\begin{vmatrix} x(n) \\ y(n) \end{vmatrix}$$

$$y_{NQ}(n+1) = Cs(n)+D\begin{vmatrix} x(n) \\ y(n) \end{vmatrix}$$

where s(n) is the status vector formed with the L accumulator outputs and Y_{NQ} is system output before the quantizer 15.

As seen below, the system coefficients must be sized for the particular channel but the converter architecture always remains the same. To change channel it therefore suffices to change the a_i, b_i, c_i, g_i coefficients. This makes possible provision of a software defined multi-standard receiver.

To facilitate analysis the quantizer of FIG 2 can be modeled like an added noise source. With this linear model the modulator output can be described as the sum of the input signal X(z) multiplied by the signal transfer function indicated by $H_X(z)$ and the quantization noise $N_q(z)$ multiplied by the noise transfer function indicated by $H_N(z)$. The choice of $H_X(z)$ and $H_N(z)$ determines univocally the values of the system coefficients {A,B,C,D} because $H_X(z)=Y_{NQ}(z)/X(z)$ with $Nq(Z)=0$, $H_N(z)=Y_{NQ}(z)/Nq(z)$ with $X(Z)=0$ and:

$$y_{NQ}(z)=[C(zI-A)^{-1}B+D]\begin{vmatrix} X(z) \\ Y_{NQ}(z)+N_q(z) \end{vmatrix}$$

Let $c_i=1\ \forall i$ and $g_i=0\ \forall i$ (it will be seen below that this choice is acceptable) and therefore:

$$H_X(z) = \frac{\sum_{i=1}^{L+1} b_i(z-1)^{i-1}}{(z-1)^L+\sum_{i=1}^{L} a_i(z-1)^{i-1}} \quad (1)$$

$$H_N(z) = \frac{(z-1)^L}{(z-1)^L + \sum_{i=1}^{L} a_i (z-1)^{i-1}} \qquad (2)$$

where L is the order of the modulator, i.e. the number of accumulators or integrators used in the structure.

Linearization of the modulator diagram permits reduction of the modulator design problem to a simpler one of design of a linear filter, i.e. finding a satisfactory form of $H_X(z)$ and $H_N(z)$. It was found that linearization of the modulator diagram is a sufficiently accurate approximation for the purposes of the present invention.

As a first consideration it can be observed that (1) and (2) require that $H_X(z)$ and $H_N(Z)$ have the same poles.

The noise transfer function is responsible for minimization of the noise within the useful band, hence maximization of the SNR.

Let $H(f)=H(e^{j2\pi fT})$; with this notation the in-band locution means $|f|\in[0,f_P]$ and the out-band locution means $|f|\in[f_S,F/2]$ with F=1/T sampling frequency.

For the noise transfer function the first design constraint comes from the necessity to obtain strong band attenuation.

We therefore require:

$$|H_N(f)|\cong 0 \text{ in-band.}$$

The $H_N(z)$ chosen must however give a functioning modulator and therefore must meet other design constraints. To ensure modulator stability it is advisable to limit gain outside the $H_N(z)$ band to less than 2. Providing a safety margin we can set:

$$|H_N(f)|\leq 1.5 \qquad \text{out-band.}$$

The signal transfer function operates on the input signal spectrum form. It is required that band gain be unitary to avoid introducing signal distortions. Therefore:

$$|H_X(f)| \cong 1 \quad \text{in-band}$$

will then be:

$$|H_X(f)| < 1 \quad \text{out-band}$$

since in accordance with the principles of the present invention the ADC converter in addition to analog-to-digital conversion must provide filtering with bandwidth near the bandwidth of the service which is to be actually received from among all those of the plurality correctly receivable from the analog stage input. This not only simplifies the digital filter's duty since the signal to be filtered will have a less burdensome interference mask but helps modulator stability since it reduces the total power of the input signal.

The design method in accordance with the innovative principles of the present invention comprises two main steps. As the first step the noise transfer function is optimized. This also permits setting the $H_X(z)$ poles which, as mentioned, are the same as those of $H_N(z)$. In the second step the zeros are optimized using advantageously the following cost function:

$$COST=\gamma\left[\int_0^{fs}(|H_X(f)|-|H_{ideal}(f)|)^2 df\right]^{1/2}+(1-\gamma)\left[\int_{fs}^{0.5}(|H_X(f)|-|H_{ideal}(f)|)^2 df\right]^{1/2}$$

on the basis of which the zeros of $H_X(z)$ are moved in such a manner as to minimize the COST function. H_{ideal} is the ideal transfer function defined as:

$$H_{ideal}(f) = \begin{cases} 1, & \text{in-band} \\ 0, & \text{out-band} \end{cases}$$

The parameter γ can be interpreted as a weight function. Reference is now made to an example in which the receiver of the present invention is provided to receive the three standards or services DECT, GSM and IS-54 and from these we choose to actually receive the GSM standard. The frequencies fp and fs for these services are:

	DECT	GSM	IS-54
fp (kHz)	576	100	12
fs (kHz)	1728	200	30

As seen, the service with the widest band is the DECT service which has a bandwidth of 1.728 MHz. Rounding, the bandwidth of the analog stage will be set at 2MHz.
FIG 3 shows the interference mask of the worst case GSM signal. The signal spectrum received is drawn with solid lines while that of the interference is drawn with dashed lines. It may be seen that the power of the channel which interests us can be more than 70dB below the interference and that this situation already appears as having to do with bandwidths less than 2MHz.
For GSM, applying the invention principles, the ADC converter also has to provide the filter function to keep the signal within 200kHz unchanged and filtering for the frequencies between 200kHz and the 2MHz upper limit.

Using the design procedure described above we obtain the poles and zeros for the noise and signal transfer functions whose corresponding frequency responses are shown in FIG 4 with $|H_N(z)|$ in dashed lines and $|H_X(z)|$ in solid lines. The in-band quantization noise attenuation level is -62dB. In addition, as seen in FIG 4 the modulator introduces a strong interference attenuation. As mentioned, this considerably simplifies the duty of the following digital filter. It is noted that as a small out-band gain was required, a notch was positioned in the $H_X(z)$ response, which aids attenuation of the adjacent interferers.
If it is desired to adapt the receiver to the IS-54 standard it suffices to recalculate the software parameters of the converter by the above described procedure. No hardware modification is necessary.
It is noted that the initial choice of letting $g_i=0\ \forall i$ implies that all the zeros of $H_N(z)$ are in z=1. This condition is immediately acceptable if the standard of actual interest has a very small standardized useful band (as for GSM and IS-54). In this case it is useful to optimize the position of the zeros of $H_N(z)$ since a satisfactory form for the spectral density of the quantization noise will be obtained even if the optimization of $H_N(z)$ is omitted.
The opposite is seemingly true when it is wanted to receive the maximum band service, DECT in the example case. Indeed, in theory the optimal converter would require optimization of the zeros of $H_N(z)$ since in the opposite case it would no longer be possible to adequately color the

quantization noise and we are forced to accept a powerful quantization noise in the useful band of the channel. It would therefore be necessary to reintroduce the g_i coefficients and give up the simplification made at the beginning.

In reality it is sufficient to position the zeros in the same position as the poles to obtain a allpass transfer function for the input signal since in the case of the maximum band service the interferers were already eliminated by the input analog stage which has a pass band sized just for this maximum band.

It is now clear that the predetermined purposes have been achieved. In accordance with the present invention there will be a single converter structure for all the standards supported and it will be adapted to a particular standard merely by changing the converter coefficients. Since the analog stage in accordance with the present invention is already adapted to treatment of all the desired standards, a receiving apparatus obtained in accordance with the present invention will be truly adaptable entirely by software to receive any one of the supported standards. In other words, in an apparatus in accordance with the present invention channel selection is initiated in the ADC conversion step. The structure described permits coloring not only the noise but the input signal also by exploiting knowledge of the input signal. Contrariwise, in known ADC converters with noise coloration it is always sought to keep the signal transfer function unitary.

Naturally the above description of an embodiment applying the innovative principles of the present invention is given by way of non-limiting example of said principles within the scope of the exclusive right claimed here. For example the standards cited in the text are only taken as examples. The capability to program the coefficients while keeping the structure unchanged to adapt the structure to different standards makes the structure modular and open to the introduction of new standards.

CLAIMS

1. A digital receiving apparatus adaptable to reception of a service from among a plurality of services and comprising in cascade an input analog section, an analog-to-digital converter and a digital signal-treatment section characterized in that the analog section has a pass band suited to treatment of a signal having bandwidth at least equal to the bandwidth of the widest channel of all the services of the plurality and in that the analog-to-digital converter in addition to analog-to-digital conversion carries out filtering with bandwidth near the bandwidth of the service selected to be actually received from among all those of the plurality.

2. Apparatus in accordance with claim 1 characterized in that the analog-to-digital converter comprises a Sigma-Delta converter.

3. Apparatus in accordance with claim 2 characterized in that in the Sigma-Delta converter the signal X(z) input to the converter is weighted with coefficients b_i and applied to adders which receive feedback weighted with coefficients $-a_i$ and coming from a digital analog converter (DAC) which in turn receives the output value Y(z) at input with an error signal output from each adder being weighted with coefficient c_i and sent to a filter to reach the adder of the next stage with a last adder having its output sent to a quantizer (15) whose output is the output Y(z) of the converter.

4. Apparatus in accordance with claim 3 characterized in that the Sigma-Delta converter is a linear system with two inputs and an output described by an assemblage of four matrices {A,B,C,D}:

$$s(n+1) = As(n)+B\begin{vmatrix} x(n) \\ y(n) \end{vmatrix}$$

$$y_{NQ}(n+1) = Cs(n)+D\begin{vmatrix} x(n) \\ y(n) \end{vmatrix}$$

where s(n) is the status vector made up with the L outputs of the accumulators in the converter and Y_{NQ} is the output of the system before the quantizer (15).

5. Apparatus in accordance with claim 4 characterized in that $c_i=1\ \forall$ and that in the converter are defined a transfer function $H_X(z)$ for the signal and a transfer function $H_N(z)$ for the noise where:

$$H_X(z) = \frac{\sum_{i=1}^{L+1} b_i(z-1)^{i-1}}{(z-1)^L+\sum_{i=1}^{L} a_i(z-1)^{i-1}}$$

$$H_N(z) = \frac{(z-1)^L}{(z-1)^L+\sum_{i=1}^{L} a_i(z-1)^{i-1}}$$

6. Apparatus in accordance with claim 5 characterized in that $|H_N(f)|\cong 0$ in-band, $|H_N(f)|\leq 2$, and preferably $\leq 1,5$, out-band, $|H_X(f)|\cong 1$ in-band, $|H_X(z)|<1$ out-band, with $H(f)=H(e^{j2\pi fT})$.

7. Method for setting operating parameters in a digital receiving apparatus adaptable to reception of a service from among a plurality of services and comprising in cascade an analog input section, an analog-to-digital converter and a section for digital treatment of the signal with the analog section supplied with a pass band suited to treating a signal with bandwidth at least equal to the bandwidth of the widest channel of all the services of the plurality and with the analog-to-digital converter which in addition to analog-to-digital conversion provides filtering with bandwidth near the bandwidth of the service selected to be actually received from among all those of the plurality with the analog-to-digital converter comprising a Sigma-Delta converter in which are definable a transfer function $H_X(z)$ for the signal and a transfer function $H_N(z)$ for the noise with the method comprising the steps of:
- optimization of the noise transfer function, and
- optimization of the zeros of the signal transfer function.

8. Method in accordance with claim 7 in which optimization of the signal transfer function zeros is done in such a way as to minimize the cost function defined as:

$$COST=\gamma\left[\int_0^{fs} (|H_X(f)|-|H_{ideal}(f)|)^2 df\right]^{1/2}+(1-\gamma)\left[\int_{fs}^{0.5} (|H_X(f)|-|H_{ideal}(f)|)^2 df\right]^{1/2}$$

with H_{ideal} representing the ideal transfer function defined as:

$$H_{ideal}(f) = \begin{cases} 1, & \text{in-band} \\ 0, & \text{out-band} \end{cases}$$

9. Method in accordance with claim 7 in which the signal and noise transfer functions are defined respectively as:

$$H_X(z) = \frac{\sum_{i=1}^{L+1} b_i(z-1)^{i-1}}{(z-1)^L + \sum_{i=1}^{L} a_i(z-1)^{i-1}}$$

$$H_N(z) = \frac{(z-1)^L}{(z-1)^L + \sum_{i=1}^{L} a_i(z-1)^{i-1}}$$

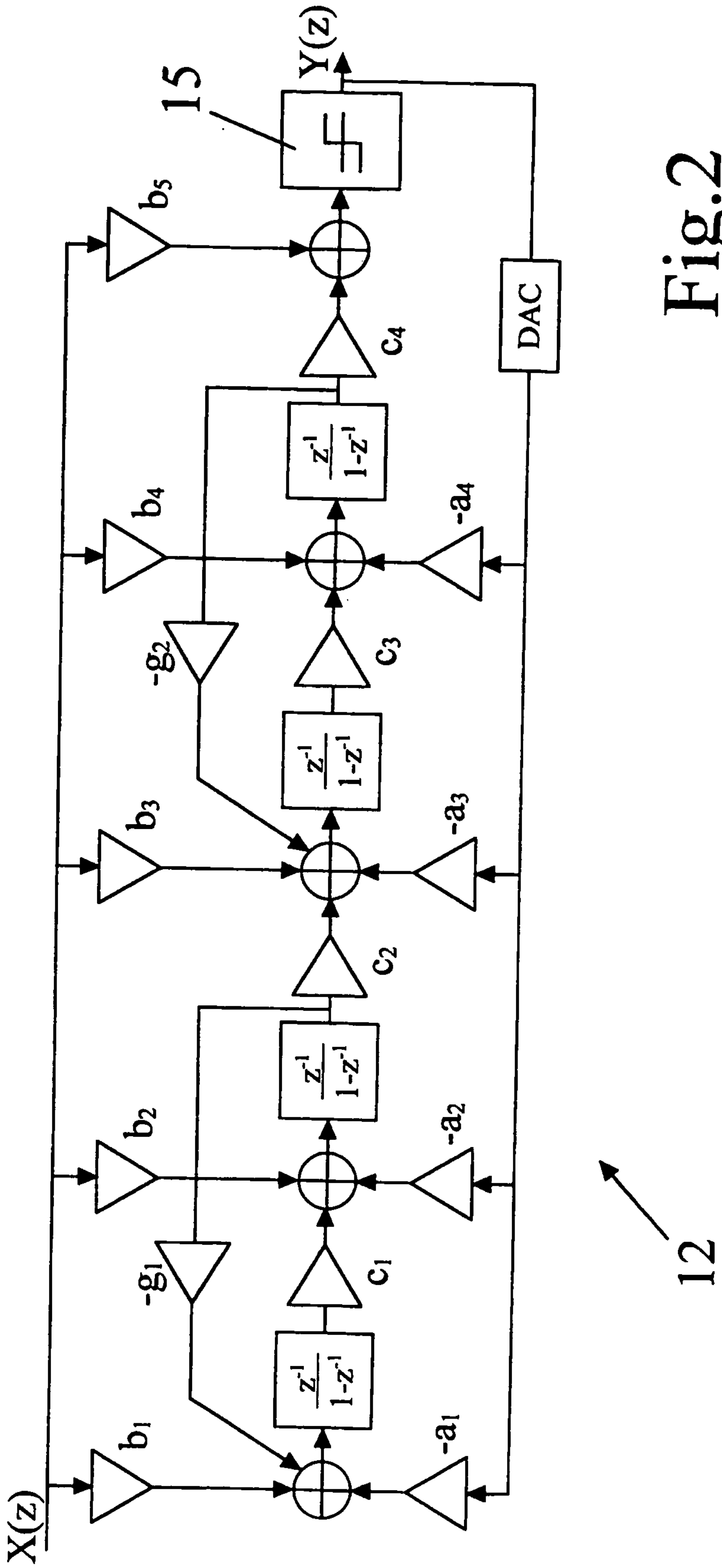
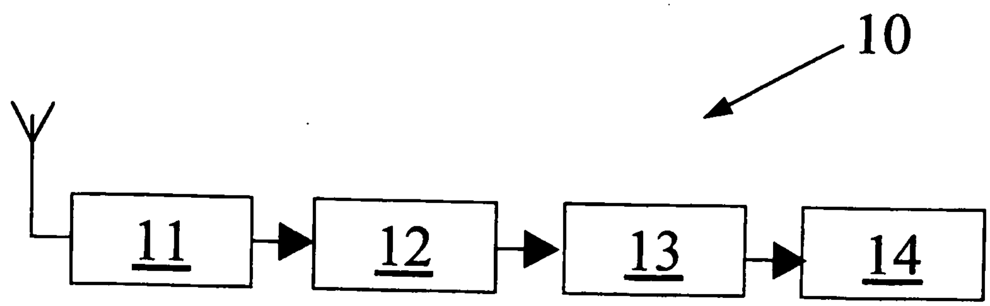


Fig.2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11
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Fig.1

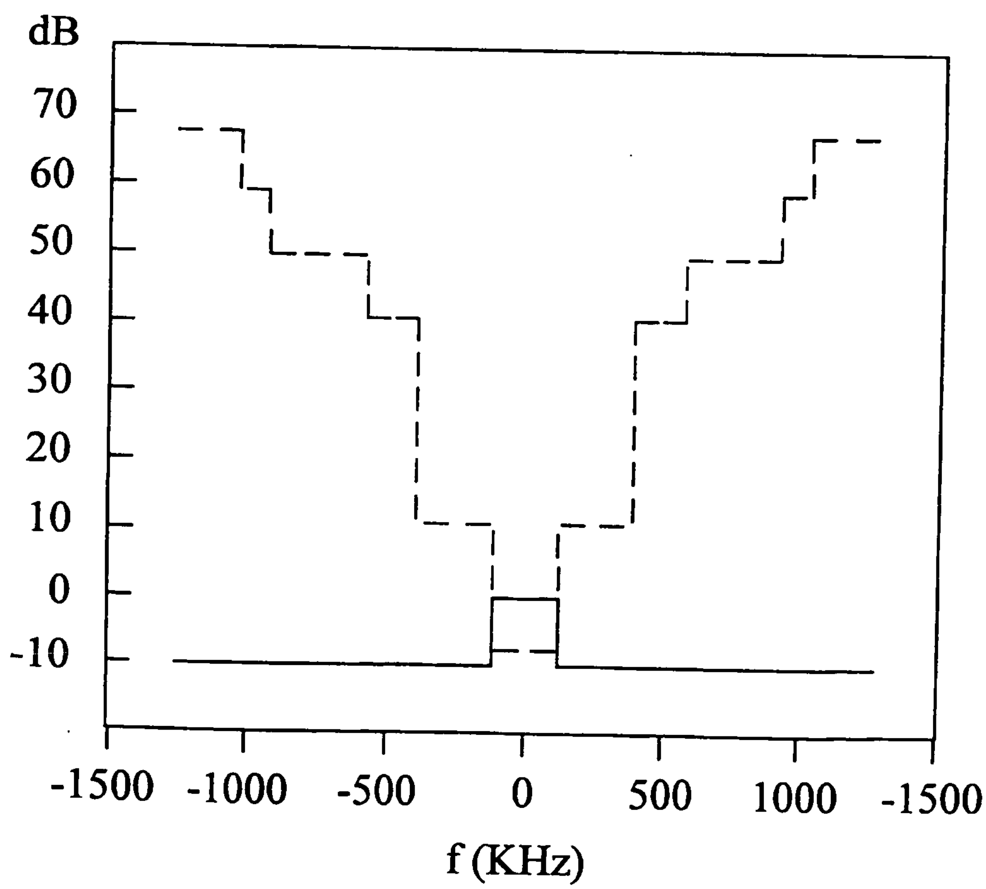
dB
70
60
50
40
30
20
10
0
-10
-1500
-1000
-500
0
500
1000
-1500
f (KHz)

Fig.3

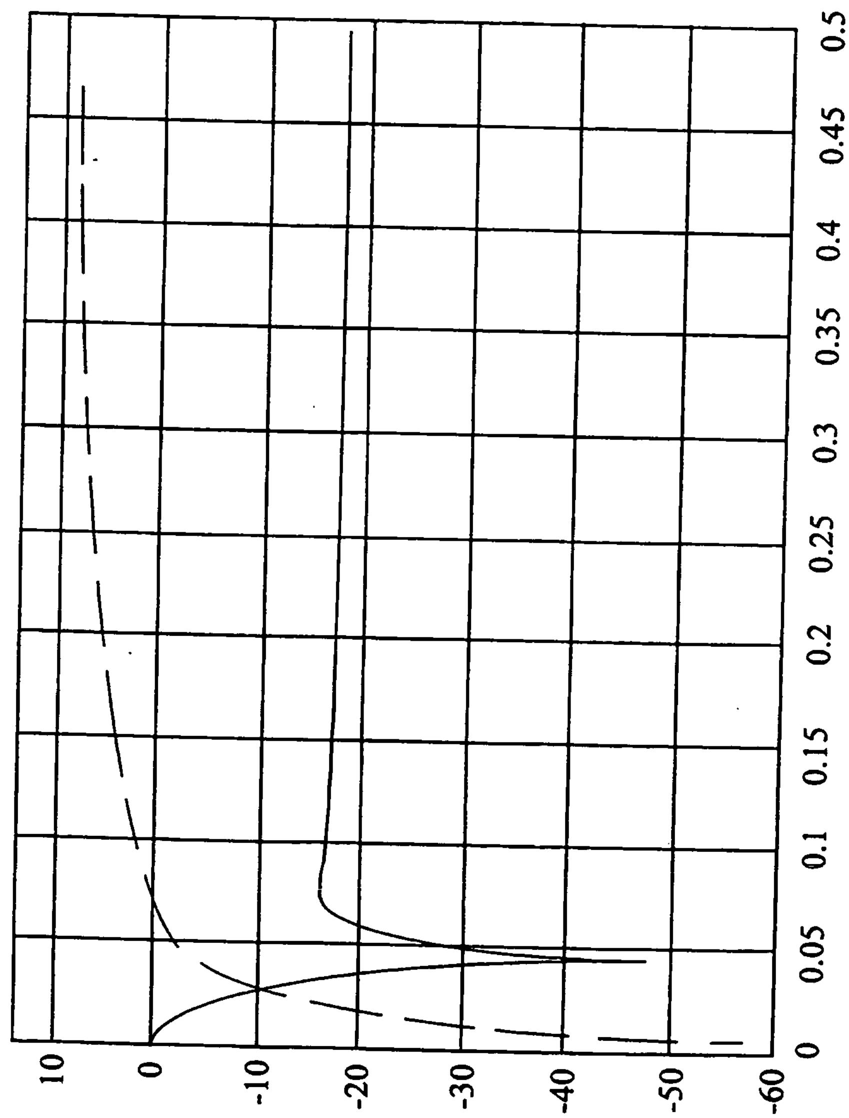

Fig.4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 00/06447

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B1/16 H03M3/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B H03M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SHENGPING YANG ET AL: "A tunable bandpass sigma-delta A/D conversion for mobile communication receiver" VTC 1994. 'CREATING TOMORROW'S MOBILE SYSTEMS'. 1994 IEEE 44TH VEHICULAR TECHNOLOGY CONFERENCE (CAT. NO.94CH3438-9), PROCEEDINGS OF IEEE VEHICULAR TECHNOLOGY CONFERENCE (VTC), STOCKHOLM, SWEDEN, 8-10 JUNE 1994, pages 1346-1350 vol.2, XP002150896 1994, New York, NY, USA, IEEE, USA ISBN: 0-7803-1927-3	1,2,7
A	column 1 -column 5	4-6,8,9
Y	figures 1,6	3

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[X] Further documents are listed in the continuation of box C. [ ] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
24 October 2000	08/11/2000
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Tzimeas, K

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Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	BOEHM K ET AL: "An IF digitizing receiver for a combined GPS/GSM terminal" PROCEEDINGS RAWCON 98. 1998 IEEE RADIO AND WIRELESS CONFERENCE (CAT. NO.98EX194), PROCEEDINGS RAWCON 98. 1998 IEEE RADIO AND WIRELESS CONFERENCE, COLORADO SPRINGS, CO, USA, 9-12 AUG. 1998, pages 39-42, XP002150897 1998, New York, NY, USA, IEEE, USA ISBN: 0-7803-4988-1	1,2
A	the whole document	3-9

X	GUNN J E ET AL: "A LOW-POWER DSP CORE-BASED SOFTWARE RADIO ARCHITECTURE" IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS,US,IEEE INC. NEW YORK, vol. 17, no. 4, April 1999 (1999-04), pages 574-590, XP000824304 ISSN: 0733-8716	1
A	column 1 -column 8 column 4	2-9

Y	JANTZI S A ET AL: "A 4TH-ORDER BANDPASS SIGMA-DELTA MODULATOR" PROCEEDINGS OF THE CUSTOM INTEGRATED CIRCUITS CONFERENCE,US,NEW YORK, IEEE, vol. CONF. 14, 3 May 1992 (1992-05-03), pages 1651-1654, XP000340923 ISBN: 0-7803-0593-0 column 1 -column 4	3
A		1,2,4-9

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